The effect of aging on luminance of standard liquid crystal display (LCD) monitors

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Objectives. The aim of this study was to evaluate the luminance level of monitors as a function of the burning time of the lamp in the monitor and further to evaluate if different areas of the monitor varied in luminance levels at a specific time.

Material and methods. Nine standard liquid crystal display (LCD) monitor models, in total 180 monitors, were evaluated. The monitors’ maximal luminance levels were measured, and the burning times of the lamps were noted. The estimated function between burning time and luminance was calculated. On 11 monitors, 9 areas distributed over the full screen were measured to evaluate the extent to which different areas had different luminance levels.

Results. Over time, the luminance decreased in all monitor models. No difference was found among the monitor models in how rapidly the luminance levels decreased. Different luminance values were found for different areas on the monitors, but no area deteriorated faster than another.

Conclusions. Standard liquid crystal display monitors undergo gradual deteriorations in luminance levels over time, and these deteriorations are correlated with the time that the monitors have been switched on. The degradation in luminance is similar over all areas of the monitors. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:237-242)

For several years, digital radiographic systems have been in use in general dentistry, and both workflow with digital intraoral receptors and their diagnostic accuracy have been evaluated systematically. 1,6 In previous surveys, it has been stated that digital systems may be more difficult to comprehend than the analog film technique because working routines (such as image capture, viewing, and archiving, as well as quality assurance of the radiographic process) are different. 4,7 Quality assurance programs should include continuous control of the receptors for physical damage and contrast and brightness control for monitors. Many dentists find these procedures cumbersome and have, therefore, handed over the quality-control process to the vendors’ technicians. 5

The final step in the technical chain from image capture to image display in digital radiography is the monitor. The American College of Radiology has specified that the luminance of a monitor to be used for primary interpretation of digital radiographs should be at least 171 cd/m² (50 foot-lamberts). 9 Studies in the medical field have evaluated cathode ray tube (CRT) monitors and found that the luminance levels degraded with long-time use of the monitors and that this degradation affected the detectability of objects with faint contrast. 9,10 Size and various quality characteristics of both CRT monitors and LCD monitors have been evaluated in dental digital radiography. 2,6,11,12 Some of these studies have shown that the diagnostic accuracy for carious lesions increased when the brightness and contrast settings of the monitor were optimized. In general dental practice, standard monitors with brightness (luminance) below 300 cd/m² are frequently used. 6,7,11 The monitors are usually switched on during the whole day, and the lights mounted inside that create the luminance may, therefore, deteriorate. This would decrease the luminance as a function of burning time of monitors.

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Table I. Monitors included in the study: brand, model, size, and numbers

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Size, inches</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>L 1720</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>HP</td>
<td>1740</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>HP</td>
<td>L 1740</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Eizo</td>
<td>L 565</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>HP</td>
<td>L 1906</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>HP</td>
<td>1940</td>
<td>19</td>
<td>5</td>
</tr>
<tr>
<td>HP</td>
<td>L 1940</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>HP</td>
<td>L 1940 T</td>
<td>19</td>
<td>44</td>
</tr>
<tr>
<td>HP</td>
<td>L 1950</td>
<td>19</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>180</td>
</tr>
</tbody>
</table>

The aim of this study was to evaluate change in screen luminance of monitors as a function of time of use.

MATERIAL AND METHODS

Nine groups of standard, LCD color monitor models, in total 180 monitors, (sizes 17 and 19 inches) from 2 manufacturers (Hewlett-Packard Company [HP], Palo Alto, CA, and Eizo Nanao Corporation, Hakusan Ishikawa, Japan) were evaluated in this study (Table I).

The luminance level for each monitor as declared by the manufacturer was used as a starting point at time 0 (Table II). The monitor’s maximal luminance, $L$ (cd/m$^2$), was measured when 100% brightness and contrast was set. The test image from task group 18 of the American Association of Physicists in Medicine (AAPM)$^{13}$ TG18-LN12-18 (Fig. 1) was used to measure the luminance level with a lux-luminance meter (Light-O-Meter, P-11, Unfors, Billdal, Sweden).

The burning time (t, hours) of the lamp in the monitor was noted. The number of hours a monitor was switched on is given under “advanced characteristics” for each monitor. The evaluated monitors all had 2 lamps on opposite sides inside the monitors.

Eleven monitors were randomly selected among the 47 of models (HP L 1950) in the study. On these monitors, 9 circular areas distributed across the screen were measured to evaluate if any difference in luminance existed in different parts of the monitor surface (Fig. 2). The test circles were located in the center and 100 pixels inside the edges of the image. The areas were chosen with regard to how an image with the size 600 × 900 pixels, approximately the amount of pixels in a “standard” intraoral digital radiograph, was shown in magnification 1:1 with the monitor resolution set at 1280 × 1024. The test circles represented commonly used areas on the monitor surface when evaluating digital radiographs. This was evaluated on 3 different occasions with, on average, 300 working hours between the measurements to determine if any area on the screen deteriorated more than another.

Regression equations were calculated to determine the relationships between burning time and luminance. The mathematical functions were calculated using Microsoft Excel (Microsoft Office XP Professional). Average luminance and standard deviation were calculated for each monitor model. To evaluate if there was any difference between brands of monitors in how fast the luminance decreased, the estimated equations were analyzed. To evaluate if different areas on the monitor had different luminance levels, all values measured were related to the center area as a percentage of the luminance obtained in the center area.

RESULTS

For all monitors, the initial luminances (as stated by the manufacturer) were between 230 and 300 cd/m$^2$ (Table II). The manufacturer of the Eizo monitor stated an initial luminance of 230, whereas the HP monitors were described as having luminances between 250 and 300, the higher luminances in the newest versions in a series. In Figs. 3 to 6, regression lines (of luminance [cd/m$^2$] on burning time in hours) are presented for the different monitors. Luminance values decreased from the initial luminance level as a function of the natural logarithm (ln) of time used. The best correlation between the luminance level and burning time of the lamp in the monitor was expressed with the equation (Table II): $L = L_0 - k \times \ln(t)$, where $L$ is the luminance value in cd/m$^2$ at a specific time, $t$, expressed in switched-on hours; $L_0$ is the initial luminance value, cd/m$^2$, stated by the manufacturers; $k$ is a constant, specific for each type of monitor; and $t$ is burning time, in hours, for 1 hour or longer.

Over time, luminance decreased in all monitors. After approximately 2000 hours, the luminance level had decreased to an average of 58% (range 51% to 64%) of the claimed initial value. No difference was found between the different models of monitors with respect to how rapidly the luminance level decreased; however, the monitors that had higher claimed luminances were found to have larger constants in their equations (Table II). This result means that when a monitor had a high initial luminance value, the value decreased faster than in a monitor with a lower initial luminance.

The standard deviation (SD) differed between 6 and 22 cd/m$^2$ (Table II). The largest SD, 22 cd/m$^2$, was caused by 2 monitors. The other high SD, 14 cd/m$^2$, was for 8 monitors, 5 of which had a switched-on time between 7000 and 9000 hours. Two of these monitors had been switched on for more than 12,000 hours.

Different luminance values were found for the various circular areas on the monitor (Fig. 7), the center of the monitor possessing the highest luminance. No area
of the monitor deteriorated faster than another; that is, the decrease in luminance was of the same magnitude in all areas over a time period.

**DISCUSSION**

The aim of this study was to evaluate if or how much the luminance levels decreased over long-time use of monitors used for display of digital dental radiographs. The results indicate that standard monitors with a claimed initial luminance level between 230 and 300 cd/m² degraded rapidly during the first 2000 hours of use. A limitation in this study was that the initial luminance level could not be verified with any other variable than the product information given by the manufacturer. This affects the constant value, \( k \), in the estimated equations.

The differences in the SDs for the mean luminance values among groups of monitors of the various brands were reasonably small. The highest SDs were in groups that had few monitors. Because of the small number of monitors in these groups, the high SDs for these groups are of limited importance. In addition, some monitors in one of these groups had been in use for considerably longer times than most of the evaluated monitors, and this resulted in larger SDs. The small SDs indicate that the evaluated groups of monitors perform quite homogeneously with respect to degradation with time.

Previous studies have concluded that it is essential to adjust brightness and contrast levels in standard monitors to increase the diagnostic accuracy for approximal carious lesions in dental digital radiographs. Studies have found that standard, color monitors when adjusted optimally provided as accurate diagnoses as gray-scale monitors specifically developed for displaying radiographs. To obtain optimal conditions for reading dental radiographs, especially faint contrast objects, the brightness and contrast levels should, in general, be lowered compared with the values that are initially set for the monitors by the manufacturers.

**Table II.** The different monitors \( L_0 \) represent the initial luminance value at time 0, \( k \) represent a constant that is characteristic for each model

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Size, inches</th>
<th>Number</th>
<th>( L_0 ) (cd/m²)</th>
<th>( k )</th>
<th>Equation (cd/m²)</th>
<th>SD (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>L 1720 17 8</td>
<td>250</td>
<td>12.0</td>
<td>( L = 250 - 12.0 \times \ln(t) )</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>1740 17 14</td>
<td>300</td>
<td>15.8</td>
<td>( L = 300 - 15.8 \times \ln(t) )</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>L 1740 17 24</td>
<td>300</td>
<td>16.5</td>
<td>( L = 300 - 16.5 \times \ln(t) )</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eizo</td>
<td>L 565 17 19</td>
<td>230</td>
<td>14.9</td>
<td>( L = 230 - 14.9 \times \ln(t) )</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>L 1906 19 2</td>
<td>270</td>
<td>14.6</td>
<td>( L = 270 - 14.6 \times \ln(t) )</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>1940 19 5</td>
<td>300</td>
<td>16.5</td>
<td>( L = 300 - 16.5 \times \ln(t) )</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>L 1940 19 17</td>
<td>250</td>
<td>13.3</td>
<td>( L = 250 - 13.3 \times \ln(t) )</td>
<td>6</td>
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<tr>
<td>HP</td>
<td>L 1940 T 19 44</td>
<td>300</td>
<td>16.6</td>
<td>( L = 300 - 16.6 \times \ln(t) )</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP</td>
<td>L 1950 19 47</td>
<td>300</td>
<td>16.4</td>
<td>( L = 300 - 16.4 \times \ln(t) )</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 1.** Test image TG18-LN12-18 from AAPM. The bright area displays the highest luminance value of the monitor.

**Fig. 2.** The 9 test areas used with an HP L 1950. One area is in the center and the other 100 pixels are inside the edges. The resolution was set to 1280 × 1024.
The luminance values decreased rather rapidly. The most rapid decrease seems to happen over the first 1000 hours. In approximately 1 year with an average switched-on time of the monitor of 10 hours per working day, the luminance level was halved. This indicates that adjustment of brightness and contrast level has to be repeated often to ensure the best possible conditions for interpreting digital radiographs. One suggestion is to have a radiographic test image as a front image on the monitor so that the operator can evaluate the monitor every time the monitor is switched on.

All areas of the screen seemed to show the same degradation in luminance over time. This result was important because many dental radiographs when displayed in 1:1 take up the full screen. This means that all parts of the screen are used for interpretation of an
The same luminance level was not, however, found in all areas of the monitor. From the center of the monitor and toward the edges, lower light emissions were observed. Whether this can affect the final outcome in the interpretation of dental digital radiographs must be further investigated.

Studies from the field of medical radiology on the luminance levels in CRT monitors have concluded that higher diagnostic performances (areas under receiver operating characteristic [ROC] curves) are obtained when high-luminance monitors are used,\textsuperscript{16,17} and it was concluded that the gradual deterioration over time in CRT monitor luminance has a detrimental effect on detection of pathologies.\textsuperscript{9} In another study, it was stated that the level of luminance is important for detection of structures with low contrast,\textsuperscript{10} and it was suggested that many monitors do not meet the quality (luminance level not below 171 cd/m\textsuperscript{2}) that is recommended by the American College of

**Fig. 5.** Four models in a series of HP monitors, all 19 inches: 98 monitors are represented. The line is the regression line, \( L = 300 - 16.5 \cdot \ln(t) \), and the dotted lines are plus or minus 1 standard deviation, 9 cd/m\textsuperscript{2}.

**Fig. 6.** HP L 1940, 17 inches: 17 monitors are marked. The line is the regression line, \( L = 300 - 16.4 \cdot \ln(t) \), and the dotted lines are plus or minus 1 standard deviation, 6 cd/m\textsuperscript{2}. 

Radiology,\textsuperscript{8} but it was also speculated that monitors with luminance levels as low as 86 cd/m\textsuperscript{2} (25 foot-lambert) might be adequate for interpretation of radiographic images. Whether or not this applies to dental digital radiography is yet to be evaluated. In this study, the luminance levels of the evaluated monitors decreased on average by 42% during the first 2000 switched-on hours. The question arises as to whether or not there is a time limit for a monitor, after which it cannot be further adjusted and must be replaced. It is essential to know at which luminance level the diagnostic accuracy in dental radiographs is unacceptable. Further attention must be given to this topic.

In medical and dental articles it has been discussed and strongly recommended that quality-control programs be implemented for digital radiographic systems.\textsuperscript{4,7,18} Luminances of all monitors diminish over time, so practitioners must determine when to acquire new ones. It follows that luminance levels of monitors that are used for displaying dental radiographs should be quantitatively measured on a regular basis and that monitors should be switched off when not in use. This means that during holidays and after a workday, the monitor should be turned off. The final image quality can never be better than the system’s weakest link.

In conclusion, a standard LCD monitor suffers from gradual deterioration in luminance level over time and this deterioration is correlated with the time that the monitor has been switched on. The degradation in luminance is similar over all areas of the screen.

REFERENCES

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